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X-ray Pulsators: Pulse Phase Spectroscopy

FINAL TECHNICAL REPORT

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The Pennsylvania State University
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Final Technical Report for NAG8-231 - X-ray Pulsators: Pulse Phase Spectroscopy

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The aim of the work funded under this grant was to apply theoretical models developed at Penn State to pulse phase resolved spectra of several X-ray binaries. This report covers the entire period of the grant.

This work was very successful and has resulted in a paper that will be published in the Astrophysical Journal and also formed a significant portion of the PhD thesis of Dr. T. Bulik who is now at the University of Chicago.

Highlights of this work are:
1) Bulik, T., Meszaros, P., Riffert, H., Makishima, K., Mihara, T. and Thomas, B. 1995, Astrophysical Journal in press:

Model calculations of inhomogeneous magnetized neutron star atmospheres were used to analyze the phase-dependent spectra of 4U1538-51 and Vela X-1 taking into account general relativistic effects. A chi2 fitting procedure was used on the Ginga data for these objects to determine the geometry and the magnetic structure of the polar caps, as well as their size and location on the surface of the stars. Other parameters determined by the fit were the masses and radii of the neutron stars, the accretion rates, and the rotation and magnetic inclination angles including an azimuthal offset to reproduce the asymmetry of the pulse shapes. It was found that general relativistic effects played a significant role in determining the derived cap sizes, the fluxes and the observational appearance of the pulses. There was evidence that the polar caps are unequal and non-antipodal, suggesting either an off-center or bent magnetic axis, or a strong non-dipole component.

The magnetic field structure was approximated by a two component model. The rotation axes were inferred to be moderately close to the mean magnetic axes, and seen at large inclinations respect to the line of sight.

2) Bulik PhD thesis:
Accretion powered X-ray pulsars were investigated in detail. Models of emission regions were developed based on the self-consistent solution of the radiative transfer together with the hydrostatic and radiative equilibrium equations. The dominant opacity is due to electron scattering in a strong magnetic field, and free-free absorption was included, the cross sections being calculated with first order relativistic corrections. Radiation pressure effects were taken

into account in detail. Estimates of the critical luminosity in the magnetic case are found to be lower than the gray Eddington luminosity. The dependence of the outgoing spectrum on the energy deposition mechanism was discussed.

X-ray pulsar light curves were simulated taking into account the effects of gravitational bending, general geometry, and a parametrized accretion cap structure. The model spectra as a function of time were compared with observations of two X-ray pulsars, 4U1538-52 and Vela X-1, and satisfactory fits are obtained. The fits suggested some anomalies in the geometry of the objects, e.g. the magnetic axes seem to be off-center, and a quite complex magnetic field structure on the caps is indicated. The accretion cap sizes were found to differ for a given pulsar, being generally compatible with theoretical models of accretion. General relativistic effects were found to be important in the formation of the spectra. The fluxes found in the fits indicated that the effects of radiation pressure cannot be neglected. This work was the first analysis of X-ray pulsar spectra as a function of phase based on a detailed physical model.